OASIS Committee Note Draft

Information Modeling with JADN Version 1.0

Committee Note Draft 01

18 January 2023

This stage:

https://docs.oasis-open.org/openc2/imjadn/v1.0/cnd01/imjadn-v1.0-cnd01.md (Authoritative)
https://docs.oasis-open.org/openc2/imjadn/v1.0/cnd01/imjadn-v1.0-cnd01.html
https://docs.oasis-open.org/openc2/imjadn/v1.0/cnd01/imjadn-v1.0-cnd01.pdf

Previous stage:

N/A

Latest stage:

https://docs.oasis-open.org/openc2/imjadn/v1.0/imjadn-v1.0.md (Authoritative)
https://docs.oasis-open.org/openc2/imjadn/v1.0/imjadn-v1.0.html
https://docs.oasis-open.org/openc2/imjadn/v1.0/imjadn-v1.0.pdf

Technical Committee:

OASIS Open Command and Control (OpenC2) TC

Chairs:

Duncan Sparrell (duncan@sfractal.com), sFractal Consulting LLC
Michael Rosa (mjrosa@nsa.gov), National Security Agency

Editors:

David Kemp (d.kemp@cyber.nsa.gov), National Security Agency

Related work:

This document is related to:

- *JSON Abstract Data Notation Version 1.0*. Edited by David Kemp. Latest stage: https://docs.oasis-open.org/openc2/jadn/v1.0/jadn-v1.0.html.

Abstract:

Information models (IMs) are used to define and generate physical data models, validate information instances, and enable lossless translation across data formats. JSON Abstract Data Notation (JADN) is a UML-based information modeling language that defines data structure independently of data format. This Committee Note describes the use of IMs, explains how to construct IMs using JADN, and contrasts IMs with other modeling approaches, such as Entity-Relationship models for databases, and knowledge models / ontologies.

Status:

This is a Non-Standards Track Work Product. The patent provisions of the OASIS IPR Policy do not apply.

This document was last revised or approved by the OASIS Open Command and Control (OpenC2) TC on the above date. The level of approval is also listed above. Check the "Latest stage" location noted above for possible later revisions of this document. Any other numbered Versions and other technical work produced by the Technical Committee (TC) are listed at https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=openc2#technical.

TC members should send comments on this document to the TC's email list. Others should send comments to the TC's public comment list, after subscribing to it by following the instructions at the "Send A Comment" button on the TC's web page at https://www.oasis-open.org/committees/openc2/.

Citation format:

When referencing this document the following citation format should be used:

[IM-JADN-v1.0]

Information Modeling with JADN Version 1.0. Edited by David Kemp. 18 January 2023. OASIS Committee Note Draft 01. https://docs.oasis-open.org/openc2/imjadn/v1.0/cnd01/imjadn-v1.0-cnd01.html. Latest stage: https://docs.oasis-open.org/openc2/imjadn/v1.0/imjadn-v1.0.html.

Notices

Table of Contents

List of Figures

1 Introduction

An Information Model (IM) defines the essential content of entities used in computing, independently of how those entities are represented (i.e., serialized) for communication or storage. This Committee Note (CN) describes the nature of an IM, and the application of the JSON Abstract Data Notation (JADN) information modeling language in the creation and use of IMs.

As an IM language, JADN is a syntax-independent, or abstract, schema language. Abstract schema languages separate structure definitions from encoding rules. JADN is oriented to work well with common Internet data formats, such as

- JSON (Javascript Object Notation)
- XML (eXtensible Markup Language)
- CBOR (Concise Binary Object Representation)

JADN is based rigorously on information theory, and an IM composed in JADN formally defines equivalence (information content) between data in different formats.

Information modeling, generally, and JADN, specifically can be applied to a broad variety of situations, such as:

- Abstract languages, such as the Open Command and Control (OpenC2) language
- Complex information structures such software bills of materials (SBOMs); examples would be the SPDX and CycloneDX SBOM formats
- Formal definition of structured information exchanges, such as are defined using the NIEM approach.

This CN discusses:

1. What is information modeling?
2. The value of an information model.
3. The distinction between an IM and other modeling approaches.
4. The creation and use of an IM using JADN and associated automated tools.

1.1 Terminology

This CN uses the definitions contained in the [JADN Specification], section 1.2.1. The following additional terms are defined for this document:

> TBD; this is a preliminary list; eliminate any terms not needed as document matures.

- **Directed Acyclic Graph:** a directed acyclic graph (DAG) is a directed graph with no directed cycles. That is, it consists of vertices and edges (also called arcs), with each edge directed from one vertex to another, such that following those directions will never form a closed loop. A directed graph is a DAG if and only if it can be topologically ordered, by arranging the vertices as a linear ordering that is consistent with all edge directions (Wikipedia)

- **Entity Relationship Model:** An entity–relationship model (or ER model) describes interrelated things of interest in a specific domain of knowledge. A basic ER model is composed of entity types (which classify the things of interest) and specifies relationships that can exist between entities (instances of those entity types). (Wikipedia)

- **Schema:** *(markup languages)* A formal description of data, data types, and data file structures, such as XML schemas for XML files. (Wiktionary)

- **Ontology:** (information science) A representation, formal naming, and definition of the categories, properties, and relations between the concepts, data, and entities that substantiate one, many, or all domains of discourse. More simply, an ontology is a way of showing the properties of a subject area and how they are related, by defining a set of concepts and categories that represent the subject. (Wikipedia)

2 Information Modeling Overview

This section discusses the nature and benefits of IMs, types of available modeling languages, and the tools that can be used in information modeling.

2.1 Information Models And Data Models

> discussion based on RFC 3444

As described in the introduction, IMs are a means to understand and document the essential information content relevant to a system, application, or protocol exchange without regard to how that information is represented in actual implementations. Having a clear view of the information required provides clarity regarding the goals that the eventual implementation must satisfy.

A small example may help clarify the concept of information. The information content of an instance can be no greater than the smallest data instance for which lossless round-trip conversion is possible. For example, an IPv4 address presented in dotted quad format is 17 bytes of JSON string data ("192.168.101.213"), but can be converted to 4 byte RFC 791 format and back without loss. The information content of an IPv4 address can therefore be no greater than 4 bytes (32 bits), and an information model would define the IPv4 address type as a byte sequence of length 4.

[RFC 3444] describes the purpose of an IM as:

> "to model managed objects at a conceptual level, independent of any specific implementations or protocols used to transport the data. ... Another important characteristic of an IM is that it defines relationships between managed objects."

In a 2008 paper on information modeling, [YTLee] describes the concept of a "conceptual schema", a "logically neutral" view of the information in a system:

> "The conceptual view is a single, integrated definition of the data within an enterprise that is unbiased toward any single application of data and independent of how the data is physically stored or accessed."

and an IM:

> "An information model is a representation of concepts, relationships, constraints, rules, and operations to specify data semantics for a chosen domain of discourse."

[RFC3444] contrasts IMs with data models (DMs):

> "Compared to IMs, DMs define managed objects at a lower level of abstraction. They include implementation- and protocol-specific details, e.g. rules that explain how to map managed objects onto lower-level protocol constructs."

and states DMs are "intended for implementors and include protocol-specific constructs".

The following key principles apply to IMs:

- An information model classifies the validity of serialized data with zero false positives and zero false negatives. That is, an information model is the authoritative definition of essential content, and any serialized data is unambiguously one of: a) consistent with, b) inconsistent with, or c) insignificant with respect to, the model.
- Information instances are values that can be compared for equality. An application compares instances in accordance with the UML properties defined by their datatype. Two instances are equal if they have the same datatype and the same value.
- If an instance can be losslessly converted among multiple serializations, then its information content is no greater than the smallest of those serializations.

2.2 Benefits of Information Models

A key point in all the IM definitions and descriptions in the previous section is the ability for the model to represent information with a focus on its *meaning*, and without concern for how that information will be represented. Focusing on meaning encourages interoperability between applications by capturing agreement about what the information conveys and how it can be used, deferring decisions on storage and transmission matters until a clear understanding of purpose has been reached. Referring back to the example of the IPv4 address, regardless of representation the address identifies the label applied to a network interface within an available address space of 2^32.

[YTLee] identifies the key benefit of an IM:

> "The advantage of using an information model is that it can provide sharable, stable, and organized structure of information requirements for the domain context."

and describes a "quality" IM as being:

- complete,
- sharable,
- stable,
- extensible,
- well-structured,
- precise, and
- unambiguous.

In DThaler's paper on *IoT Bridge Taxonomy*, which addresses the challenges created when "many organizations develop and implement different schemas for the same kind of things", the concluding Recommendations section includes the following:

> To ... increase semantic interoperability, it is desirable that different data models for the same type of thing (e.g., light bulbs) are as similar as possible for basic functionality. In an ideal world, data models used by different protocols and organizations would express exactly the same information in ways that are algorithmically translatable by a dynamic schema bridge with no domain-specific knowledge. Sharing data models more widely, and having agreements in principle of at least using the same abstract information model, would be very beneficial.

The notion of "express[ing] exactly the same information in ways that are algorithmically translatable" is a fundamental purpose of information modeling.

2.3 Information Modeling Languages

[YTLee] describes an IM language as follows:

> "An information modeling language is a formal syntax that allows users to capture data semantics and constraints."

and defines their importance:

> "Formal information modeling languages that describe information requirements unambiguously is an enabling technology that facilitates the development of a large scale, networked, computer environment that behaves consistently and correctly."

RFC 8477, *Report from IoT Semantic Interoperability Workshop 2016*, describes a lack of consistency across Standards Developing Organizations (SDOs) in defining application layer data, attributing it to the lack of an encoding-independent standardization of the information represented by that data. The JADN information modeling language is intended to address that gap. Abstract Syntax Notation One (ASN.1) is another example of an abstract schema language.

JADN is a syntax-independent schema language, based on UML datatypes. JADN is designed to work with common Internet data formats (JSON, XML, CBOR), providing a schema to support them. JADN is also graph oriented to align with the web and database design practices - the concept of primary and foreign keys (URLs) is fundamental.

JADN's native format is structured JSON, and a broad variety of tools exist for creating and manipulating information in JSON format.

- a JADN schema is structured data that can be generated and transformed programmatically
- JADN schemas employ a simple, regular structure (every type definition has the same five fields)

> ASN.1 description from ITU-T Introduction, excerpted from https://www.itu.int/en/ITU-T/asn1/Pages/introduction.aspx

ASN.1 is a formal notation used for describing data transmitted by telecommunications protocols, regardless of language implementation and physical representation of these data, whatever the application, whether complex or very simple. The notation provides a certain number of pre-defined basic types, and makes it possible to define constructed types. Subtyping constraints can be also applied on any ASN.1 type in order to restrict its set of values. Data described in ASN.1 is serialized and deserialized based on set of encoding rules, which are defined for a broad variety of formats including the Basic Encoding Rules (BER) and similar, which are closely associated with ASN.1, as well as less closely tied standards such as XML and JSON.

> What languages aren't really IM languages

Other languages have been used for information modeling, although that is not their primary purposes. Some examples are

- UML
- IDEF1X

2.4 Information Modeling Tools

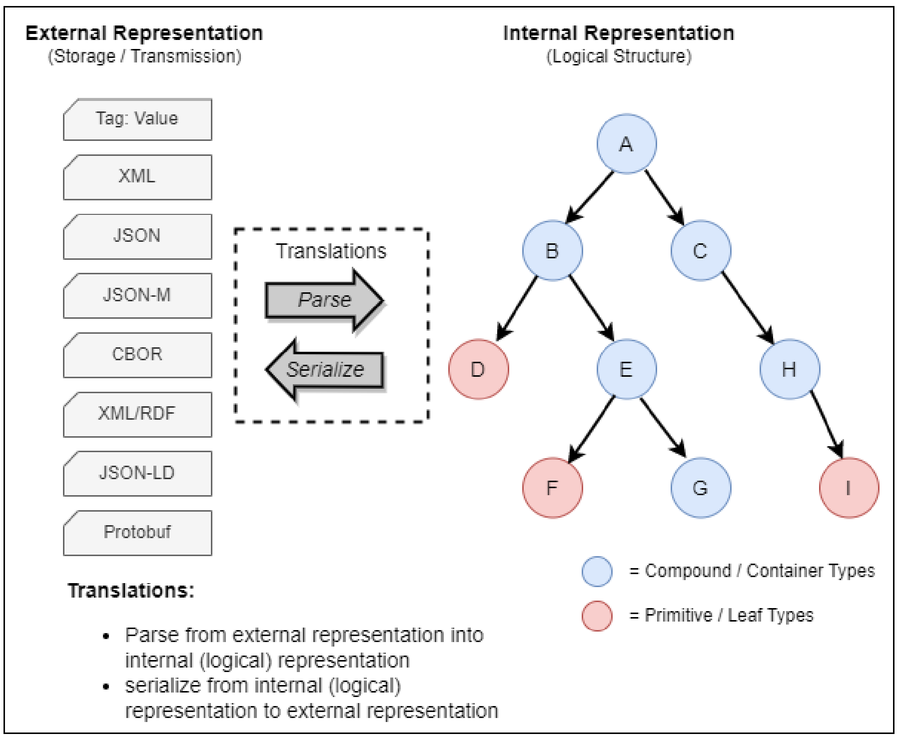
The value of an IM language multiplies when automated tooling is available to support creation, maintenance, and use of models created in that language. The need for tools is discussed in [RFC 8477], citing particularly the need for code generation and debugging tools. A tool set to support an IM language should provide

- Model creation capabilities
- Model validation capabilities
- Translation among alternative representations of the IM (e.g., textual, graphical)
- Generation of language-specific schemas from an IM
- Model translation to language- or protocol-specific serialization / deserialization capabilities

2.5 Applying an Information Model

A primary application of an IM is in the translation of data into and out of in-memory representation and serialized formats for storage and transmission. The IM defines the types, organization, and validation requirements for the information manipulated by an application or protocol. Within an application the IM is instantiated through the data structures and types supported by the chosen programming language. The IM also guides the creation of routines to parse and validate data being input from storage or through communications, and to serialize data being output to storage or transmission. Deriving the processing capabilities from the IM ensures consistency as the data is manipulated. Figure 2-1 illustrates the concept of applying an IM to manage the associated data.

Figure 2-1 -- Parsing and Serializing With An IM



The internal representation, illustrated in Figure 2-1 as a tree, is guided by rules associated with applying the IM:

- the internal representation conforms to the IM
- each node in the internal representation has an abstract core type from the IM
- each core type has associated serialization rules for each external representation format

The JADN Specification defines 12 core types, which are described in Section 3.1.6 of this CN. The JADN Specification also defines serialization rules for JSON (with three levels of verbosity) and CBOR [RFC7409]. Supporting a new data format ("external representation") requires defining serialization rules to translate each core type to that data format.

As an example, consider an information element defined as a boolean type, which is the simplest core type. The essential nature of a boolean is that it is limited to only two values, usually identified as "true" and "false". However, the *data* representing a Boolean value is determined by serialization rules, and could be any of "false" and "true", 0 and 1, "n" and "y", etc. In a programming language, many variable types and values may evaluate as "true":

- Non-zero integers
- Non-empty strings
- Non-empty arrays

An abstract representation of an IM does not capture data types and values for a Boolean node, e.g. integer 0 or 37 or string "yes". It has only the characteristics of the node type: false or true. A JSON representation can use a Boolean type with values 'false' and 'true', but for efficient serialization might also use the JSON number type with values 0 and 1.

3 Creating Information Models with JADN

This section provides a brief overview of JADN, and describes the use of JADN in information modeling.

3.1 JADN Overview

The JADN information modeling language was developed against specific objectives:

1. Core types represent application-relevant "information", not "data"
2. Single specification unambiguously defines multiple data formats
3. Specification uses named type definitions equivalent to property tables
4. Specification is data that can be serialized
5. Specification has a fixed structure designed for extensibility

As described in the JADN specification introduction:

> JADN is a formal description technique that combines type constraints from the Unified Modeling Language (UML) with data abstraction based on information theory and structural organization using results from graph theory.

> EDITOR'S NOTE: consider whether the following adds clarity or confusion; it might need to be re-written to guide the reader through the concepts a bit more.

From UML JADN takes the concept of modeling information/data using Simple Classifiers (see UML, 10.2 Datatypes) as opposed to the common practice of using Structured Classifiers (UML, 11.4 Classes) which do not define data in a unique way that can be validated and signed. The JADN use of the UML primitive types defined in UML, Table 21.1, can be found in Appendix D.1.

The [JADN Specification] defines twelve base types:

Primitive:

- Binary
- Boolean
- Integer
- Number
- String

Compound:

- Array
- ArrayOf
- Map
- MapOf
- Record

Selection / Union:

- Enumerated
- Choice

Each of the compound types is a *container*, a named group of related items such as the latitude and longitude of a geographic coordinate, or the set of properties of an object. In addition to its individual items, every container has *multiplicity* attributes, including limits on the number of items, whether the items have a sequential ordering, and whether duplicate items are allowed.

The JADN compound type and its options are chosen for an IM based on the information characteristics to be modeled:

- Array and ArrayOf contain a group of values.
- Map, MapOf and Record contain a group of keys and corresponding values (a mapping)
- All items in ArrayOf and MapOf groups have the same value (and key) type
- Each item in Array, Map, and Record groups has an individual value (and key) type

and the decision tree for which compound type to use is:

Value / Mapping	Same / Individual	JADN Type

Value / Mapping	Same / Individual	JADN Type
Value	Same	ArrayOf(ValueType)
Value	Individual	Array
Key:Value	Same	MapOf(KeyType, ValueType
Key:Value	Individual	Map or Record

For the last information type - containers of individually-defined key:value pairs - JADN provides two types: Map and Record. The difference is that Record keys have a sequential ordering while Map keys do not. Map instances are always serialized as key:value pairs, while Record instances may be serialized as either key:value pairs or table rows with values in column position, depending on data format.

For example if Location is a Record type with name, state, latitude and longitude keys, its instances are serialized using *verbose* JSON data format as:

```
[
  {
    "name": "St. Louis",
    "state": "Missouri",
    "latitude": "38.627003",
    "longitude": "-90.199402"
  },
  {
    "name": "Seattle",
    "state": "Washington",
    "latitude": "47.60621",
    "longitude": "-122.33207"
  }
]
```

The same Record values are serialized using *compact* JSON data format (where the columns are 1: name, 2: state, 3: latitude, 4: longitude) as:

```
[
  ["St. Louis", "Missouri", "38.627003", "-90.199402"],
  ["Seattle", "Washington", "47.60621", "-122.33207"]
]
```

If Location is a Map type, its instances are always serialized as key:value pairs regardless of data format.

**

Another significant UML concept is that JADN distinguishes among all four multiplicity types (UML, Table 7.1), while logical models typically support only sets. JADN's interpretation of this is summarized in the Table 3-1.

Table 3-1 – Multiplicity Types

	Ordered	Unordered
Unique	Ordered Set, Record JADN: ArrayOf+*unique*	Set, Map JADN: ArrayOf+*set*, MapOf
Non-Unique	Sequence, List JADN: ArrayOf	Bag JADN: ArrayOf+*unordered*

JADN accepts the UML philosophy that schemas are classifiers that take a unit of data and determine whether it is an instance of a datatype, and recognizes the idea of generalization (UML, 9.9.7) through use of the Choice type.

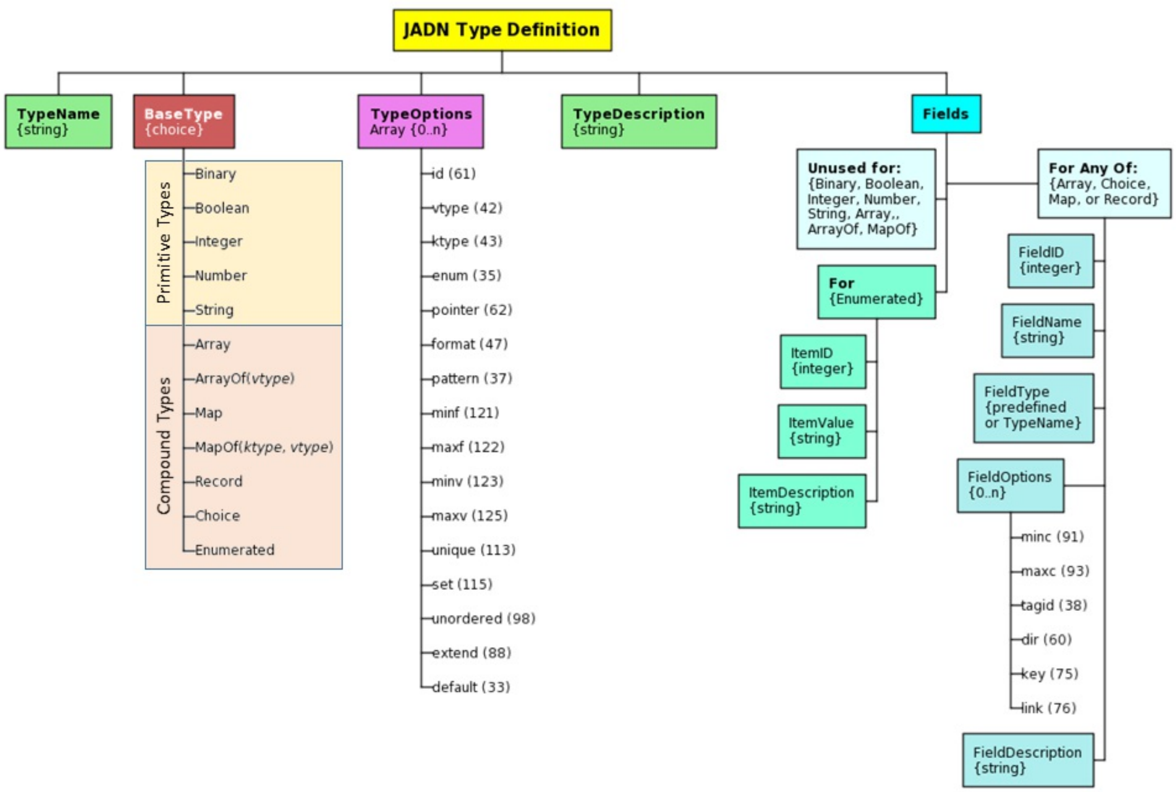
Beyond these UML concepts, JADN recognizes that information models are directed graphs with a small predefined set of base datatypes and only two kinds of relationship: "contain" and "reference".

3.1.1 Type Definitions

Figure 3-1 summarizes the structure of a JADN Type Definition, and identifies values for each of the five elements in the definition. The five elements are:

1. A **TypeName**, which is simply a string used to refer to that type.
2. The **BaseType** of the type, which is one of either the five "Primitive" (or, alternatively, "scalar") types or the seven "Compound" types, as shown in Figure 3-1.
3. Zero or more of the available JADN **TypeOptions** that refine the base types to fit particular needs.
4. An optional **TypeDescription** string that provides additional information about the type.
5. For any of the Compound types, a set of **Item** or **Field** options that define the items that comprise the compound type.

Figure 3-1 -- JADN Type Definition Structure



A firm requirement of JADN is that a TypeName must not be a JADN predefined type. There are also conventions intended to improve the consistency and readability of JADN specifications. These conventions are defined in JADN but can be overridden within a JADN schema if desired (see section 3.1.2 of the [JADN Specification]):

- **TypeNames** are written in PascalCase or Train-Case (using hyphens) with an initial upper case letter, and are limited to 64 upper case, lower case or numeric characters, or the "system" character (used for tool-generated type definitions).
- **FieldNames** are written in camelCase or snake_case (using underscores) with an initial lower case letter, and are limited to 64 upper case, lower case or numeric characters.
- **Name space identifiers** (nsids) are limited to 8 upper case, lower case or numeric characters and must begin with a letter.
- The **"system character"** (which defaults to `$`) is used by JADN processing tools when generating derived types while processing a JADN model; it is not normally used by JADN schema authors.

3.1.2 TypeOptions

The third element of a JADN type definition is zero or more of the TypeOptions defined in section 3.2.1 of the [JADN Specification]. TypeOptions are classifiers that, along with the base type, determine whether data values are instances of the defined type. For example, the *pattern* TypeOption is used with the String BaseType to define valid instances of that string type using a regular expression conforming to [ECMAScript] grammar.

The following is the complete set of type options:

Option	Type	Description
id	Boolean	Items and Fields are denoted by FieldID rather than FieldName
vtype	String	Value type for ArrayOf and MapOf
ktype	String	Key type for MapOf
enum	String	Extension: Enumerated type derived from a specified type
pointer	String	Extension: Enumerated type pointers derived from a specified type
format	String	Semantic validation keyword
pattern	String	Regular expression used to validate a String type
minf	Number	Minimum real number value
maxf	Number	Maximum real number value
minv	Integer	Minimum integer value, octet or character count, or element count
maxv	Integer	Maximum integer value, octet or character count, or element count
unique	Boolean	ArrayOf instance must not contain duplicate values
set	Boolean	ArrayOf instance is unordered and unique
unordered	Boolean	ArrayOf instance is unordered
extend	Boolean	Type is extensible; new Items or Fields may be appended
default	String	Default value

Detailed explanations of each type option can be found in Sections 3.2.1.1-12 of the [JADN Specification].

The following table summarizes the applicability of type options to JADN base types.

	Binary	Boolean	Integer	Number	String	Array	ArrayOf	Map	MapOf	Record	Choice	Enumerated
id								X			X	X
vtype							X		X			
ktype									X			
enum												X
pointer												X
format	X		X	X	X	X						
pattern					X							
minf				X								

	Binary	Boolean	Integer	Number	String	Array	ArrayOf	Map	MapOf	Record	Choice	Enumerated
maxf				X								
minv	X		X		X	X	X	X	X	X		
maxv	X		X		X	X	X	X	X	X		
unique							X					
set							X					
unordered							X					
extend						X		X		X	X	X
default												

3.1.3 Item Or Field Definitions

The use of the **Fields** element to convey Item or Field Definitions is dependent on the **BaseType** selected, as illustrated in Figure 3-1. The rules pertaining to the **Fields** array are as follows:

- If the **BaseType** is a Primitive type, ArrayOf, or MapOf, the **Fields** array MUST be empty:
- If the **BaseType** is Enumerated, each item definition in the **Fields** array MUST have three elements:
    1. **ItemID:** the integer identifier of the item
    2. **ItemValue:** the string value of the item
    3. **ItemDescription:** a non-normative comment
- If the **BaseType** is Array, Choice, Map, or Record, each field definition in the **Fields** array MUST have five elements:
    1. **FieldID:** the integer identifier of the field
    2. **FieldName:** the name or label of the field
    3. **FieldType:** the type of the field, a predefined type or a TypeName with optional Namespace ID prefix **NSID:TypeName**
    4. **FieldOptions:** an array of zero or more **FieldOption** or **TypeOption** ([JADN Specification] sections 3.2.2, or 3.2.1, respectively) applicable to the field
    5. **FieldDescription:** a non-normative comment

3.1.4 Field Options

Compound types containing Items or Fields support field options in addition to the type options describe in Section 3.1.2. JADN defines six field options.

Option	Type	Description	JADN Specification Section
minc	Integer	Minimum cardinality, default = 1, 0 = optional	3.2.2.1
maxc	Integer	Maximum cardinality, default = 1, 0 = default max, >1 = array	3.2.2.1
tagid	Enumerated	Field containing an explicit tag for this Choice type	3.2.2.2
dir	Boolean	Pointer enumeration treats field as a group of items	3.3.5
key	Boolean	Field is a primary key for this type	3.3.6
link	Boolean	Field is a foreign key reference to a type instance	3.3.6

Type options can also apply to fields, with the constraint that the type option must be applicable to the field's type, as described in the base type examples in Section 3.1.6.

3.1.5 JADN Representations

The native format of JADN is JSON, but JADN content can be represented in others ways that are often more useful for documentation. This section describes the JSON content used for each of the JADN basic types, and then illustrates the other representations using a simple example.

3.1.5.1 Native JSON Representation

This section illustrates the JSON representations of the Base Type described in Section 3.1. Depictions are provided for each of three ways that the **Fields** array is used, depending on the base type used in a particular type definition.

Figure 3-2 illustrates the structure of JADN for defining any Primitive **BaseType**, or ArrayOf or MapOf type; for all of these the **Fields** array is empty:

Figure 3-2 -- JADN for Primitive, ArrayOf, MapOf Types

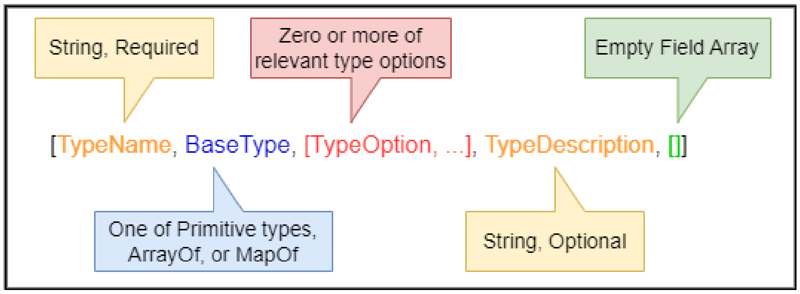


Figure 3-3 illustrates the structure of JADN for defining an Enumerated **BaseType**; for enumerations each item definition in the **Fields** array has three elements:

Figure 3-3 -- JADN for Enumerated Types

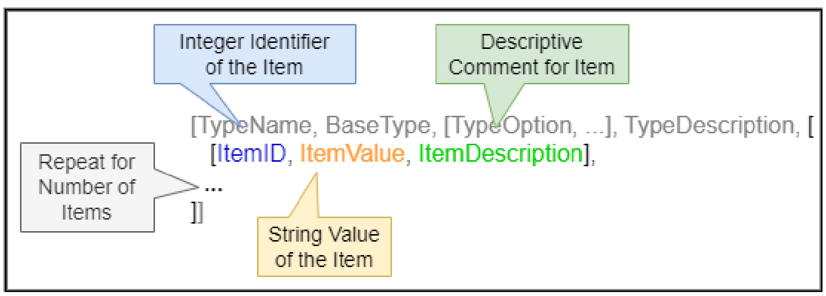
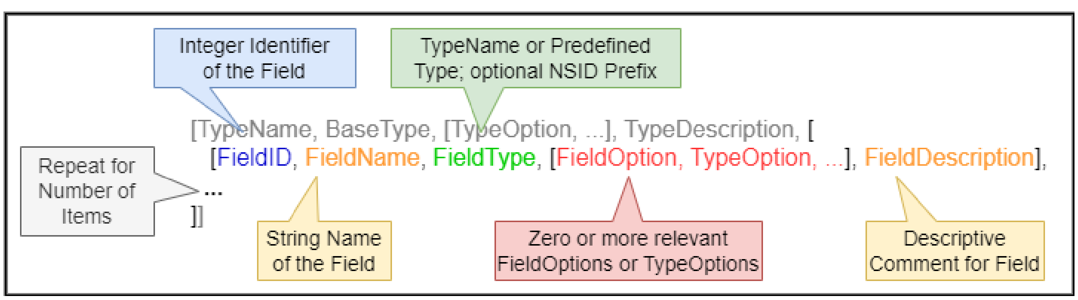


Figure 3-4 illustrates the structure of JADN for defining a **BaseType** of Array, Choice, Map, or Record; for these types each field definition in the **Fields** array has five elements:

Figure 3-4 -- JADN for Types with Fields



3.1.5.2 Alternative JADN Representations

The [JADN Specification] identifies three formats (Section 5) in addition to the native format:

- JADN Interface Definition Language (JIDL)
- Table Style
- Entity Relationship Diagrams (ERDs)

The formal definitions of each of these types are found in sections 5.1, 5.2, and 5.3, respectively, of the [JADN Specification].

Automated tooling makes it straightforward to translate among all four of these formats in a lossless manner, and each format has its advantages:

- JADN in native JSON format can be readily processed by common JSON tooling.
- JADN in table style presentation is often used in specifications (e.g., as property tables such as are commonly found in specifications).
- JADN presented in entity relationship diagrams aids with visualization of an information model.
- JADN in JIDL format, a simple text structure, is easy to edit, making it a good format for both the initial creation and the documentation of a JADN model. JIDL is also more compact than table style presentation.

When defining elements of type Array or Enum.ID in JIDL, no field names are used. These types are defined using a field ID and a TypeName. For documentation and debugging purposes a FieldName can be included in the JIDL comment field, immediately following the `//` and followed by a double colon delimiter (i.e., `::`). For more information see the [JADN Specification] descriptions of Field Identifiers (section 3.2.1.1) and JADN-IDL format (section 5.1). Here is a brief JIDL example of this format:

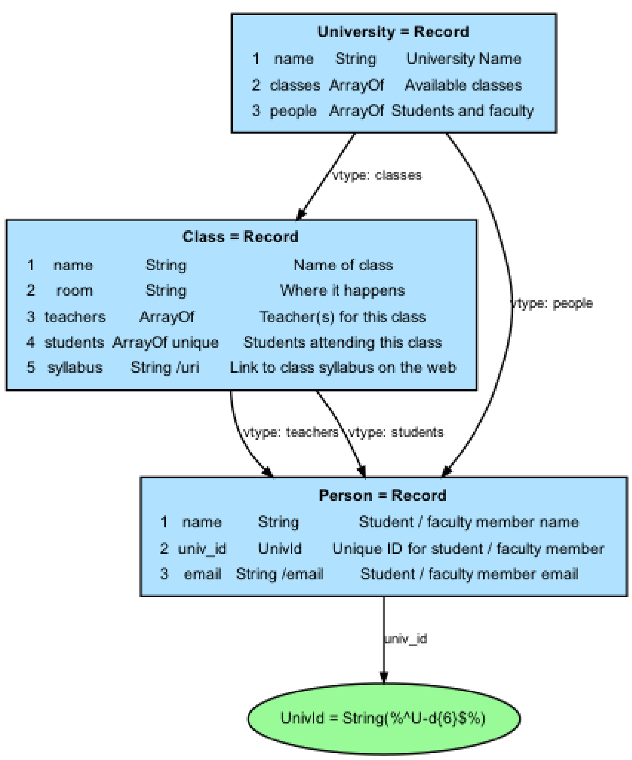
```
Publication-Data = Array         // who and when of publication
    1 String           // label:: name of record label
    2 String /date     // rel_date:: and when did they let this drop
```

3.1.5.3 Multiple Representation Example

This section uses a slightly extended version of an example IM based on the University ERD shown in Section 5.3 of the JADN Specification to illustrate the representations described in Section 3.1.5.2. The example begins with the ERD for the model:

Figure 3-5 -- Simple University Example ERD

> NOTE: Placeholder ERD for modified "University" example. To be replaced with version without description fields.



The package (see Section 4.1) containing the JADN corresponding to the above ERD is shown here:

Figure 3-6 -- Simple University Example JADN (JSON format)

```
{
 "info": {
  "package": "http://example.com/uni",
```

```
  "exports": ["University"]
 },
 "types": [
  ["University", "Record", [], "A place of learning", [
    [1, "name", "String", [], "University Name"],
    [2, "classes", "ArrayOf", ["*Class"], "Available classes"],
    [3, "people", "ArrayOf", ["*Person"], "Students and faculty"]
  ]],
  ["Class", "Record", [], "Pertinent info about classes", [
    [1, "name", "String", [], "Name of class"],
    [2, "room", "String", [], "Where it happens"],
    [3, "teachers", "ArrayOf", ["*Person", "L"], "Teacher(s) for this class"],
    [4, "students", "ArrayOf", ["*Person", "L", "q"], "Students attending this class"],
    [5, "syllabus", "String", ["/uri "], "Link to class syllabus on the web"]
  ]],
  ["Person", "Record", [], "", [
    [1, "name", "String", [], "Student / faculty member name"],
    [2, "univ_id", "UnivId", ["K"], "Unique ID for student / faculty member"],
    [3, "email", "String", ["/email"], "Student / faculty member email"]
  ]],
  ["UnivId", "String", ["%^U-\\d{6}$"], "University ID (U-nnnnnn)", []]
 ]
}
```

Converting the JSON to JIDL yields a representation that is both more readable and easier to edit:

Figure 3-7 -- Simple University Example JADN (JIDL format)

```
 package:  "http://example.com/uni"
 exports:  ["University"]

University = Record                       // A place of learning
    1 name     String                     // University Name
    2 classes  ArrayOf(Class){0..*}       // Available classes
    3 people   ArrayOf(Person){0..*}      // Students and faculty

Class = Record                                      // Pertinent info about classes
    1 name      String                              // Name of class
    2 room      String                              // Where it happens
    3 teachers  ArrayOf(Person){0..*}               // Teacher(s) for this class
    4 students  ArrayOf(Person){0..*} unique        // Students attending this class
    5 syllabus  String /uri                         // Link to class syllabus on the web

Person = Record
    1 name     String          // Student / faculty member name
    2 univ_id  UnivId          // Unique ID for student / faculty member
    3 email    String /email   // Student / faculty member email

UnivId = String (%^U-\d{6}$%)  // University ID (U-nnnnnn)
```

Property tables are a common representation of data structures in specifications. JADN is easily converted to property tables, which are quite readable but somewhat more challenging to edit than JIDL (the package information has been omitted from the set of property tables).

Figure 3-8 -- Simple University Example JADN (table format)

Type: University (Record)

ID	Name	Type	#	Description
1	**name**	String	1	University Name

ID	Name	Type	#	Description
2	**classes**	ArrayOf(Class)	1	Available classes
3	**people**	ArrayOf(Person)	1	Students and faculty

Type: Class (Record)

ID	Name	Type	#	Description
1	**name**	String	1	Name of class
2	**room**	String	1	Where it happens
3	**teachers**	ArrayOf(Person)	1	Teacher(s) for this class
4	**students**	ArrayOf(Person) unique	1	Students attending this class
5	**syllabus**	String /uri	1	Link to class syllabus on the web

Type: Person (Record)

ID	Name	Type	#	Description
1	**name**	String	1	Student / faculty member name
2	**univ_id**	UnivId	1	Unique ID for student / faculty member
3	**email**	String /email	1	Student / faculty member email

Type Name	Type Definition	Description
UnivId	String (%^U-\d{6}$%)	University ID (U-nnnnnn)

Finally, the code to generate the ERD presented at the beginning of the example is easily generated from the JADN model. In this specific example code for the widely-used GraphViz tool is provided, however the HTML to generate the label tables for the three nodes has been excerpted for readability.

Figure 3-9 -- Simple University Example ERD Source Code (GraphViz)

```
# package: http://example.com/uni
# exports: ["University"]

digraph G {
    graph [fontname=Times fontsize=12]
    node [fillcolor=lightskyblue1 fontname=Arial fontsize=8 shape=box style=filled]
    edge [arrowsize=0.5 fontname=Arial fontsize=7 labelangle=45.0 labeldistance=0.9]
    bgcolor=white

    n0 [label=<
        <table ...>
      > shape=rectangle]
      n0 -> n1 [label="vtype: classes"]
      n0 -> n2 [label="vtype: people"]

    n1 [label=<
        <table ...>
      > shape=rectangle]
      n1 -> n2 [label="vtype: teachers"]
      n1 -> n2 [label="vtype: students"]
```



```
    n2 [label=<
        <table ...>
      > shape=rectangle]
      n2 -> n3 [label=univ_id]

    n3 [label="UnivId = String(%^U-\d{6}$%)" fillcolor=palegreen shape=ellipse]
}
```

3.1.6 Base Type Examples

This section provides illustrative examples of the JADN base types. For each type, the definition from the [JADN Specification] is quoted, the relevant type options are listed, and an example is provided using the JADN and JIDL formats.

3.1.6.1 Binary

Definition: A sequence of octets. Length is the number of octets.

TypeOptions: The *minv*, *maxv*, and *format* TypeOptions are applicable to the Binary data type.

Example: The Binary type is used for representing arbitrary binary data. An information item fitting a Binary type would be defined as follows:

```
["FileData", "Binary", [], "Binary contents of file", []]
```

The corresponding JIDL representation would be:

```
// Example JIDL definition of a binary datatype
  FileData = Binary   // Binary contents of file
```

> EDITOR'S NOTE: need examples of applying the TypeOptions

3.1.6.2 Boolean

Definition: An element with one of two values: true or false.

TypeOptions: No TypeOptions are applicable to the Boolean data type.

Example: The Boolean type is used for representing bi-valued (i.e., true/false, yes/no, on/off) information. An information item fitting a Boolean type would be defined as follows:

```
["AccessGranted", "Boolean", [], "Result of access control decision", []]
```

The corresponding JIDL representation would be:

```
// Example JIDL definition of a boolean datatype
  AccessGranted = Boolean   // Result of access control decision
```

3.1.6.3 Integer

Definition: A positive or negative whole number.

TypeOptions: The *minv*, *maxv*, and *format* TypeOptions are applicable to the Integer data type.

Example: The Integer type is used for representing numerical information with discrete integer values. An information item fitting an Integer type would be defined as follows:

```
["TrackNumber", "Integer", [], "Track number for current song", []]
```

The corresponding JIDL representation would be:

```
// Example JIDL definition of an Integer datatype
  TrackNumber = Integer   // Track number for current song
```

> EDITOR'S NOTE: need examples of applying the TypeOptions

3.1.6.4 Number

Definition: A real number.

TypeOptions: The *minf*, *maxf*, and *format* TypeOptions are applicable to the Number data type.

Example: The Number type is used for representing numerical information with continuous values. An information item fitting a Number type would be defined as follows:

```
["Temperature", "Number", [], "Current temperature observation in degrees C", []]
```

The corresponding JIDL representation would be:

```
// Example JIDL definition of an Number datatype
  Temperature = Number   // Current temperature observation in degrees C
```

> EDITOR'S NOTE: need examples of applying the TypeOptions

3.1.6.5 String

Definition: A sequence of characters, each of which has a Unicode codepoint. Length is the number of characters.

TypeOptions: The *minv*, *maxv*, *format*, and *pattern* TypeOptions are applicable to the String data type.

Example: The String type is used for representing information best presented as text. An information item fitting a String type would be defined as follows:

```
["TrackTitle", "String", [], "Title of the song in the selected track", []]
```

The corresponding JIDL representation would be:

```
// Example JIDL definition of an String datatype
  TrackTitle = String   // Title of the song in the selected track
```

> EDITOR'S NOTE: need examples of applying the TypeOptions

When applying the *pattern* option in JIDL, it should be directly connected to the String TypeName. The entire pattern specification is surrounded with braces "{}", containing `pattern="REGEX"` where `REGEX` is the regular expression that governs the format of the string.

```
Barcode = String{pattern="^\d{12}$"}    // A UPC-A barcode is 12 digits
```

3.1.6.6 Enumerated

Definition: A vocabulary of items where each item has an id and a string value.

TypeOptions: The *id*, *enum*, *pointer*, and *extend* TypeOptions are applicable to the Enumerated data type.

Example: The Enumerated type is used to represent information that has a finite set of applicable values. An information item fitting the Enumerated type would be defined as follows:

```
["L4-Protocol", "Enumerated", [], "Value of the protocol (IPv4) or next header (IPv6)
field in an IP packet. Any IANA value, [[RFC5237]](#rfc5237)", [
    [1, "icmp", "Internet Control Message Protocol - [RFC0792]"],
    [6, "tcp", "Transmission Control Protocol - [RFC0793]"],
    [17, "udp", "User Datagram Protocol - [RFC0768]"],
    [132, "sctp", "Stream Control Transmission Protocol - [RFC4960]"]
]]
```

The corresponding JIDL representation would be:

```
// Example JIDL definition of an Enumerated datatype
L4-Protocol = Enumerated  // Value of the protocol (IPv4) or next header (IPv6)
                          // field in an IP packet. Any IANA value per RFC5237
   1 icmp                 // Internet Control Message Protocol - [RFC0792]
   6 tcp                  // Transmission Control Protocol - [RFC0793]
  17 udp                  // User Datagram Protocol - [RFC0768]
```



```
132 sctp                 // Stream Control Transmission Protocol - [RFC4960]
```

> EDITOR'S NOTE: need examples of applying the TypeOptions

3.1.6.7 Choice

Definition: A discriminated union: one type selected from a set of named or labeled types.

TypeOptions: The *id* and *extend* TypeOptions are applicable to the Choice data type.

Example: The Choice type is used to represent information limited to selecting one type from a defined set of named or labeled types. An information item fitting the Choice type would be defined as follows:

```
["IdentityType", "Choice", [], "Nature of the referenced identity", [
  [1, "person", "Person", [], "Identity refers to a person"],
  [2, "organization", "Organization", [], "Identity refers to an organization"],
  [3, "tool", "Tool", [], "Identity refers to an automated tool"]
]]
```

The corresponding JIDL representation would be:

```
// Example JIDL definition of a Choice datatype
IdentityType = Choice                // Nature of the referenced identity
   1 person          Person          // Identity refers to a person
   2 organization    Organization    // Identity refers to an organization
   3 tool            Tool            // Identity refers to an automated tool
```

> EDITOR'S NOTE: need examples of applying the TypeOptions

3.1.6.8 Array

Definition: An ordered list of labeled fields with positionally-defined semantics. Each field has a position, label, and type.

TypeOptions: The *extend*, *minv*, *maxv*, and *format* TypeOptions are applicable to the Array data type.

Example: The Array type is used to represent information where it is appropriate to group related information elements together, even if the elements of the array are heterogeneous. Each element in the array is defined as a field, using the field definitions described in Section 3.1.3 and refined using the field options described in Section 3.1.4. An information item fitting the Array base type would be defined as follows:

```
  ["IPv4-Net", "Array", ["/ipv4-net"], "IPv4 address and prefix length", [
    [1, "ipv4_addr", "IPv4-Addr", [], "IPv4 address as defined in [[RFC0791]](#rfc0791)"],
    [2, "prefix_length", "Integer", ["[0"], "CIDR prefix-length. If omitted, refers to a 
single host address."]
  ]]
```

Note this example also uses a type option for semantic validation (the `ipv4-net` keyword). The corresponding JIDL representation would be:

```
// Example JIDL definition of an Array datatype with heterogenous elements
// the IPv4-Net type is an array used to represent a CIDR block

IPv4-Net = Array /ipv4-net   // IPv4 address and prefix length
   1  IPv4-Addr              // ipv4_addr:: IPv4 address as defined in RFC0791
   2  Integer optional       // prefix_length:: CIDR prefix-length. If omitted, refers to 
a single host address.
```

> EDITOR'S NOTE: need examples of applying the TypeOptions

3.1.6.9 ArrayOf(*vtype*)

Definition: A collection of fields with the same semantics. Each field has type *vtype*. Ordering and uniqueness are specified by a collection option.

TypeOptions: The *vtype*, *minv*, *maxv*, *unique*, *set*,and *unordered* TypeOptions are applicable to the ArrayOf data type.

Example: The ArrayOf type is used to represent information where it is appropriate to group a set of uniform information elements together. The fields if the array are defined by the *vtype*, which can be primitive or compound. An information item fitting the ArrayOf base type would be defined as follows:

> EDITOR'S NOTE: need examples of applying the TypeOptions

3.1.6.10 Map

Definition: An unordered map from a set of specified keys to values with semantics bound to each key. Each key has an id and name or label, and is mapped to a value type.

TypeOptions: The *id*, *extend minv*, and *maxv* TypeOptions are applicable to the Map data type.

Example: The Map type is used to represent information that can be represented as (key, value) pairs. Another term for this type of information structure is an "associative array". The Map base type always uses an integer identifier as the key, with each integer associated with a specific value. An information item fitting the Map type would be defined as follows:

```
  ["Hashes", "Map", ["{1"], "Cryptographic hash values", [
    [1, "md5", "Binary", ["/x", "{16", "}16", "[0"], "MD5 hash as defined in [[RFC1321]]
(#rfc1321)"],
    [2, "sha1", "Binary", ["/x", "{20", "}20", "[0"], "SHA1 hash as defined in [[RFC6234]]
(#rfc6234)"],
    [3, "sha256", "Binary", ["/x", "{32", "}32", "[0"], "SHA256 hash as defined in
[[RFC6234]](#rfc6234)"]
  ]]
```

The corresponding JIDL representation would be:

```
// Example JIDL definition of an Map datatype
Hashes = Map{1..*}     // Cryptographic hash values
   1 md5        Binary{16..16} /x optional    // MD5 hash as defined in RFC1321
   2 sha1       Binary{20..20} /x optional    // SHA1 hash as defined in RFC6234
   3 sha256     Binary{32..32} /x optional    // SHAs26 hash as defined in RFC6234
```

> EDITOR'S NOTE: need examples of applying the TypeOptions

3.1.6.11 MapOf(*ktype*,*vtype*)

Definition: An unordered map from a set of keys of the same type to values with the same semantics. Each key has key type *ktype*, and is mapped to value type *vtype*.

TypeOptions: The *ktype*, *vtype*, *minv*, and *maxv* TypeOptions are applicable to the MapOf data type.

Example: The MapOf type is used to represent information that can be represented as (key, value) pairs, where the types for the keys and the values in the MapOf are of specific types and are defined using type options. MapOf is suitable when the collection of items can't be represented as an enumeration, such as the connection of employee identification numbers to employees. An information item fitting the MapOf type would be defined as follows:

```
[
  ["Employees","MapOf", ["EID","Employee"], "Maps employee identifier numbers to employee
information", []],

  ["EID", "Integer", ["{0","}1000"], "will need new system when exceed 1,000 employees",
[]],

  ["Employee", "Record","", "Employee Information",[
    [1, "name", "String", "", "Usually First M. Last"],
    [2, "start_date", "Date", "", "always record start date"],
    [3, "end_date", "Date", ["[0"], "if end_date is present = former employee"]
  ]],
```



```
  ["Date", "String", ["/date"], "", []]
]
```

The corresponding JIDL representation would be:

```
// Example JIDL definition of a MapOf datatype
// Maps employee identifier numbers to employee information
Employees = MapOf(EID, Employee)

// Employee identifier numbers
EID = Integer{0..1000}        // will need new system when exceed 1,000 employees

// Employee information
Employee = Record
  1 name        String         // usually "First M. Last"
  2 start_date  Date           // always record start date
  3 end_date    Date optional  // if end_date is present = former employee

Date = String /date
```

> EDITOR'S NOTE: need examples of applying the TypeOptions

3.1.6.12 Record

Definition: An ordered map from a list of keys with positions to values with positionally-defined semantics. Each key has a position and name, and is mapped to a value type. Represents a row in a spreadsheet or database table.

TypeOptions: The *extend*, *minv*, and *maxv* TypeOptions are applicable to the Record data type.

Example: The Record type is used to represent information that has a consistent repeated structure, such as a database record. Elements of a record can be accessed by either position or value.

```
  ["IPv4-Connection", "Record", ["{1"], "5-tuple that specifies a tcp/ip connection", [
    [1, "src_addr", "IPv4-Net", ["[0"], "IPv4 source address range"],
    [2, "src_port", "Port", ["[0"], "Source service per RFC6335"],
    [3, "dst_addr", "IPv4-Net", ["[0"], "IPv4 destination address range"],
    [4, "dst_port", "Port", ["[0"], "Destination service per RFC6335"],
    [5, "protocol", "L4-Protocol", ["[0"], "Layer 4 protocol (e.g., TCP)"]
  ]]
```

The corresponding JIDL representation would be:

```
// Example JIDL definition of a record datatype
// the IPv4-Connection type is a record

IPv4-Connection = Record{1..*}                   // 5-tuple that specifies a tcp/ip 
connection
   1 src_addr         IPv4-Net optional          // IPv4 source address range
   2 src_port         Port optional              // Source service per RFC6335
   3 dst_addr         IPv4-Net optional          // IPv4 destination address range
   4 dst_port         Port optional              // Destination service per RFC6335
   5 protocol         L4-Protocol optional       // Layer 4 protocol (e.g., TCP)
```

> EDITOR'S NOTE: need examples of applying the TypeOptions

3.2 Information Modeling Process

> rough outline, starting from YTLee paper
> https://www.nist.gov/publications/information-modeling-design-implementation

1. Define the scope of the model, identifying the domain of discourse and the processes to be supported by the IM.
2. Conduct a requirements analysis to define information requirements.
3. Develop the model, transforming information requirements into a conceptual model. This may employ a top-down, bottom-up,

or mixed / inside-out approach.
4. Group concepts to identify units of functionality
5. Structure information requirements into entities, objects, or classes
6. Capture the model in the chosen modeling language

> Alternate approach, from Frederiks / van der Weide
> https://www.sciencedirect.com/science/article/abs/pii/S0169023X05000753

Process has two roles (which may be filled by groups):

- A **Domain Expert**: someone with superior detailed knowledge of the Universe of Discourse (UoD) but often minor powers of abstraction from that same UoD
- A **System Analyst**: someone with superior powers of abstraction, but limited knowledge of the UoD.

Process has four phases:

1. *Elicitation*: used to drive creation of a requirements document, an informal specification in natural language.
2. *Modeling*: the creation of a conceptual model based on the requirements document.
3. *Verification*: confirmation that the formal specification correctly applies the formal syntax rules of the chosen modeling technique.
4. *Validation*: confirmation with the domain expert that the formal model properly represents the requirements document.

The process is executed in an iterative sequence of modeling, verification and validation. At least one iteration of the modeling loop is required.

3.3 Information Modeling Example

Possible example subjects:

- University (people, departments, classes, buildings, rooms, schedules) -- extension from diagram in JADN Spec
- Shopping Website (customers, accounts, catalogs, carts, payment processing, shipping)
- Vehicle Rental Management (customers, accounts, vehicles, rentals, check-out, check-in, billing)
- Boutique Manufacturer (catalog, customization options, supply chain, orders, builds, shipping)
- Website Message Board (users, accounts, forums, threads, messages)
- Simplified SBOM (start from SPDX3 model and limit to high-level aspects)
- SDO management system (similar to OASIS Kavi)
- Music Database (artists, albums, songs, tracks, metadata, guest artists)

3.3.1 Example 1: A Digital Music Library

This example shows a simple IM for a digital music library. The components of the library are described here along with the associated JIDL. The ERD for the library appears at the end of this section. The complete, consolidate JADN, JIDL, and property tables can be found in Appendix E.1.

The model assumes that each track is stored as a file with its audio in one of several formats. The library organizes tracks into albums, which are associated with a UPC-A barcode (a 12-digit number). The model is loosely based on the ID3 metadata used with MP3 audio files.

At the top level, the library is map of barcodes to albums.

```
       title: "Music Library"
     package: "http://fake-audio.org/music-lib"
     version: "1.0"
 description: "This information model defines a library of audio tracks, organized by album"
     license: "CC0-1.0"
     exports: ["Library"]


// Top level of the library is a map of CDs by barcode
Library = MapOf(barcode, Album){1..*}

Barcode = String{pattern="^\d{12}$"}     // A UPC-A barcode is 12 digits
```


Each album is then represented by a record of artist, title, publication data, cover art and an array of individual audio tracks. Multiple digital image formats are supported for the cover art.

```
Album = Record                          // model for the album
    1 artist    Artist                  // artist associated with this album
    2 title     String                  // commonly known title for this album
    3 pub_data  Publication-Data        // metadata about album publication
    4 tracks    ArrayOf(Track)[1..*]    // individual track descriptions
    5 cover_art Cover-Art               // cover art image for this album

Publication-Data = Record       // who and when of publication
    1 label     String          // name of record label
    2 rel_date  String /date    // and when did they let this drop

Cover-Art = Record              // pretty picture for the album
    1 i_format  Image-Format    // what type of image file?
    2 i_content Binary          // the image data in the identified format

Image-Format = Enumerated extend        // can only be one, but can extend list
    1 PNG
    2 JPG
```

Artists have a name and one or more associated instruments that they perform on.

```
Artist = Record                                  // interesting information about the 
performers
    1 artist_name   String                       // who is this person
    2 instruments   ArrayOf(Instrument)[1..*]    // and what do they play

Instrument = Enumerated extend   // collection of instruments (non-exhaustive)
    1 vocals
    2 guitar
    3 bass
    4 drums
    5 keyboards
    6 percussion
    7 brass
    8 woodwinds
    9 harmonica
```

Each track is stored in a file, and has a track number within the album, title, length, potentially "featured" artists, and the audio data. Multiple digital audio formats are supported for the audio content.

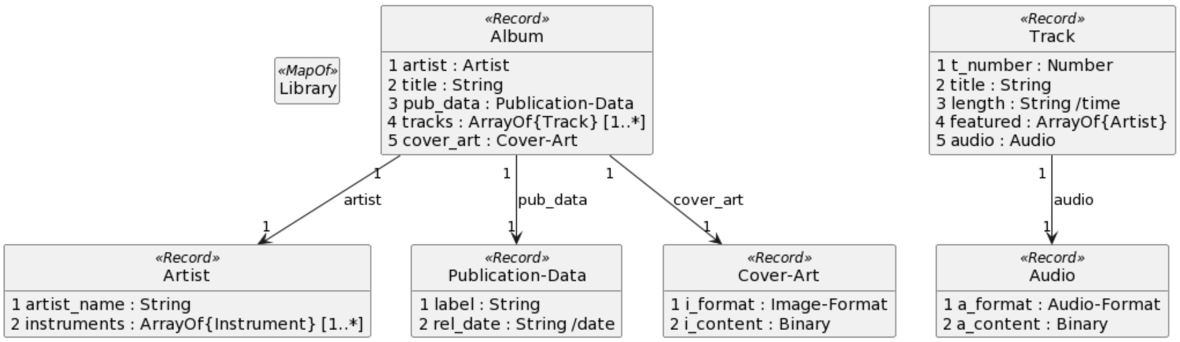
```
Track = Record                  // information about the individual audio tracks
    1 t_number  Integer{0..*}   // track sequence number
    2 title     String          // track title
    3 length    String /time    // length of track
    4 featured  ArrayOf(Artist) // important guest performers
    5 audio     Audio           // the all important content

Audio = Record          // information about what gets played
    1 a_format  Audio-Format    // what type of audio file?
    2 a_content Binary          // the audio data in the identified format

Audio-Format = Enumerated extend    // can only be one, but can extend list
    1 MP3
    2 OGG
    3 FLAC
```

The entity relationship diagram in Figure 3-10 illustrates how the model components connect.

Figure 3-10 -- Music Library Example ERD



4 Advanced Techniques

4.1 Namespaces, Packages, and Referencing

> discuss how JADN IMs may be broken into components (packages) and connections made between components (namespaces & referencing)

4.1.1 Packages

> complex models are divided into packages

> package header defined in JADN spec section 6

> essential information element of package header is namespace

> packages can explicitly export types defined within; this isn't a rigorous public / private type distinction, but provides a means for schema authors to indicate the intended public types, and allows JADN schema tools to detect discrepancies

4.1.2 Namespaces

> Namespace Identifier (NSID) by default is a 1-8 character string beginning with a letter and containing only letters and numbers. Default formatting can be overridden by inserting an alternative definition into a JADN schema

> A namespace is associated with a package, and used in other packages to refer to types defined in that package

> JADN uses the common convention of using the NSID followed by a colon to link an item to the namespace where it is defined (e.g., NSID:TypeName)

4.1.3 Referencing

4.1.4 Linking Between Projects

4.2 From Logical Models to IMs

Appendix A. Informative References

This appendix contains the informative references that are used in this document.

While any hyperlinks included in this appendix were valid at the time of publication, OASIS cannot guarantee their long-term validity.

(Reference sources: For references to IETF RFCs, use the approved citation formats at: http://docs.oasis-open.org/templates/ietf-rfc-list/ietf-rfc-list.html. For references to W3C Recommendations, use the approved citation formats at: http://docs.oasis-open.org/templates/w3c-recommendations-list/w3c-recommendations-list.html. Remove this note before submitting for publication.)

[DThaler]

"IoT Bridge Taxonomy", D. Thaler, submission to Internet of Things (IoT) Semantic Interoperability (IOTSI) Workshop 2016, https://www.iab.org/wp-content/IAB-uploads/2016/03/DThaler-IOTSI.pdf

[ECMAScript]

CMA International, "ECMAScript 2018 Language Specification", ECMA-262 9th Edition, June 2018, https://www.ecma-international.org/ecma-262.

[JADN-v1.0]

JSON Abstract Data Notation Version 1.0. Edited by David Kemp. 17 August 2021. OASIS Committee Specification 01. https://docs.oasis-open.org/openc2/jadn/v1.0/cs01/jadn-v1.0-cs01.html. Latest stage: https://docs.oasis-open.org/openc2/jadn/v1.0/jadn-v1.0.html.

[JSON-Schema]

"JSON Schema, a vocabulary that allows you to annotate and validate JSON documents.", retrieved 9/26/2022, https://json-schema.org/

[OWL-Primer]

"OWL 2 Web Ontology Language Primer (Second Edition)", retrieved 10/25/2022, https://www.w3.org/TR/owl-primer/

[RFC3444]

Pras, A., Schoenwaelder, J., "On the Difference between Information Models and Data Models", RFC 3444, January 2003, https://tools.ietf.org/html/rfc3444.

[RFC7049]

Bormann, C., Hoffman, P., *"Concise Binary Object Representation (CBOR)"*, RFC 7049, October 2013, https://tools.ietf.org/html/rfc7049.

[RFC8477]

Jimenez, J., Tschofenig, H., and D. Thaler, "Report from the Internet of Things (IoT) Semantic Interoperability (IOTSI) Workshop 2016", RFC 8477, DOI 10.17487/RFC8477, October 2018, https://www.rfc-editor.org/info/rfc8477.

[RFC8610]

Birkholz, H., Vigano, C. and Bormann, C., "Concise Data Definition Language (CDDL): A Notational Convention to Express Concise Binary Object Representation (CBOR) and JSON Data Structures", RFC 8610, DOI 10.17487/RFC8610, June 2019, https://www.rfc-editor.org/info/rfc8610

[UML]

"Unified Modeling Language", Version 2.5.1, December 2017, https://www.omg.org/spec/UML/2.5.1/About-UML/

[YTLee]

Lee, Y. (1999), Information Modeling: From Design to Implementation, IEEE Transactions on Robotics and Automation, [online], https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=821265 (Accessed October 5, 2022)

Appendix B. Acknowledgments

(Note: A Work Product approved by the TC must include a list of people who participated in the development of the Work Product. This is generally done by collecting the list of names in this appendix. This list shall be initially compiled by the Chair, and any Member of the TC may add or remove their names from the list by request. Remove this note before submitting for publication.)

B.1 Special Thanks

Substantial contributions to this document from the following individuals are gratefully acknowledged:

Participant Name, Affiliation or "Individual Member"

B.2 Participants

The following individuals have participated in the creation of this document and are gratefully acknowledged:

OpenC2 TC Members:

First Name	Last Name	Company
Philippe	Alcoy	Arbor Networks
Darren	Anstee	Arbor Networks
Michelle	Barry	AT&T
Brian	Berliner	Symantec Corp.
Adam	Bradbury	EclecticIQ
Joe	Brule	National Security Agency
Michael	Butt	NC4
Toby	Considine	University of North Carolina at Chapel Hill
Trey	Darley	New Context Services Inc.
David	Darnell	North American Energy Standards Board
Sudeep	Das	McAfee
Andrea	De Bernardi	Moviri SPA
Blake	Essing	AT&T
Alex	Everett	University of North Carolina at Chapel Hill
Joyce	Fai	National Security Agency
Travis	Farral	Anomali
David	Girard	Trend Micro
Andy	Gray	ForeScout
John-Mark	Gurney	New Context Services Inc.
Stefan	Hagen	Individual
David	Hamilton	AT&T
Nick	Humphrey	Huntsman Security

First Name	Last Name	Company
Christian	Hunt	New Context Services Inc.
April	Jackson	G2
Sridhar	Jayanthi	Individual
Bret	Jordan	Symantec Corp.
Jason	Keirstead	IBM
David	Kemp	National Security Agency
David	Lemire	G2
Jason	Liu	Northrop Grumman
Radu	Marian	Bank of America
Danny	Martinez	G2
Lisa	Mathews	National Security Agency
James	Meck	FireEye Inc.
Efrain	Ortiz	Symantec Corp.
Paul	Patrick	FireEye Inc.
Michael	Pepin	NC4
Nirmal	Rajarathnam	ForeScout
Chris	Ricard	Financial Services Information Sharing and Analysis Center (FS-ISAC)
Daniel	Riedel	New Context Services Inc.
Jason	Romano	National Security Agency
Philip	Royer	Splunk Inc.
Thomas	Schreck	Siemens AG
Duane	Skeen	Northrop Grumman
Duncan	Sparrell	sFractal Consulting LLC
Michael	Stair	AT&T
Andrew	Storms	New Context Services Inc.
Gerald	Stueve	Fornetix
Rodney	Sullivan	NCI Agency
Allan	Thomson	LookingGlass
Bill	Trost	AT&T
Raymon	van der Velde	EclecticIQ
Jyoti	Verma	Cisco Systems
David	Waltermire	NIST

First Name	Last Name	Company
Jason	Webb	LookingGlass
Sean	Welsh	AT&T
Charles	White	Fornetix
Sounil	Yu	Bank of America
Vasileios	Mavroeidis	University of Oslo

Appendix C. Revision History

Revision	Date	Editor	Changes Made
filename-v1.0-wd01	yyyy-mm-dd	Editor Name	Initial working draft

Appendix D. Frequently Asked Questions (FAQ)

This appendix responds to a variety of Frequently Asked Questions regarding JADN.

D.1 JADN vs. UML Primitive Data Types

[UML] section 21 says "The PrimitiveTypes package is an independent package that defines a set of reusable PrimitiveTypes that are commonly used in the definition of metamodels." JADN defines an additional Binary type (a sequence of octets/bytes) because it is needed. Unlike UML, JADN does not define a separate type for UnlimitedNatural because the Integer type can be given upper and lower bounds, and natural numbers are the set of non-negative integers. The equivalent in JADN uses Integer{0..*} for natural numbers, and the Integer value -1 for the "unlimited" value (*) of UnlimitedNatural.

Table D-1 maps basic data types between UML and JADN.

UML	JADN
Integer	Integer
Boolean	Boolean
String	String
UnlimitedNatural	Integer {0..*}
Real	Number
xxx	Binary

D.2 Why JADN and not RDF?

This section discusses the relationship between JADN and RDF, and why RDF does not serve the purpose of an Information Model

Comment

The following comment was submitted in response to the OASIS JADN public review:

> *Have you considered the following specifications from W3C: **RDF, RDFS, JSON-LD, SHACL**? RDF, RDFS (and potentially OWL and BFO) should take care of your information modelling needs, JSON-LD provides a JSON serializations, SHACL provides extensive validation capabilities. I would be interested to see the analysis why these technologies were eliminated after your consideration.*

Response

The short answer (RDF models *knowledge* while JADN models *information*) is provided in the JADN introduction:

> *UML class models and diagrams are commonly referred to as "Data Models", but they model knowledge of real-world entities using classes. In contrast, information models model data itself using datatypes.*

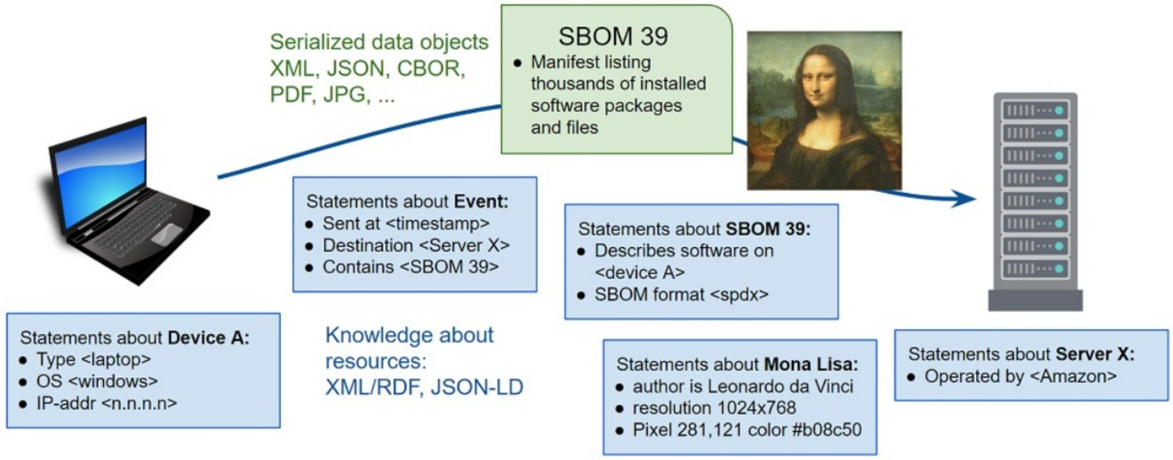
An RDF graph is a knowledge model / ontology consisting of (subject, predicate, object) triples, where each member of the triple can be an International Resource Identifier (IRI), blank node, or literal. An RDF triple encodes a statement—a simple logical expression, or claim about the world. A JADN graph, in contrast, consists of DataType definitions that define the information content of data instances.

In order to understand why RDF is not suitable as an information modeling language, one must understand two things about information:

1. **Information** distinguishes *significant* data from *insignificant* data. (In Shannon's original context signal and noise are in the analog domain, but entropy is meaningful even in purely digital communication.)

2. Information defines *loss*. Lossless transformations across data formats preserve information; after a round trip significant data is unchanged and insignificant data can be ignored. A lossy round trip is lossy not because it alters data, but because it alters significant data.

Information models define the information capacity of data instances; two data formats are *equivalent* if conversion between them is lossless.



Resources can be physical or digital entities. Both can be subjects of knowledge model statements, but only digital resources can be modeled as information instances and serialized for transmission and storage. The RDF primer contains the following example statements about resources:

- <Bob> <is a> <person>.
- <Bob> <is a friend of> <Alice>.
- <Bob> <is born on> <the 4th of July 1990>.
- <Bob> <is interested in> <the Mona Lisa>.

From context we can infer that <the Mona Lisa>, like <Bob> and <Alice>, is intended to be a physical resource.

Extreme Example

The physical painting can never be serialized losslessly, because even a multi-band 3D camera that captures near-infrared images of pencil sketches beneath the paint and elevation contours of the brush strokes still does not capture, for example, the chemical and physical properties of the canvas, pencils, washes, pigments, binders, or other materials used in the painting. But though physical entities can never be modeled completely as data, camera images of them can be. A 1920x1080 image contains 2 million pixels that could be serialized in the lossless PNG format, or as 2 million XML/RDF statements of the form <mona lisa pixel 192,13> <has color> <#32b82f>. The raw image data can be serialized as RDF and deserialized back to raw without loss, but is it useful to do so? RDF is useful for statements like the painting was created by da Vinci in 1503-1506, is housed in the Louvre, depicts a smiling woman, and has cedar trees in the background. But if an application needs the image, PNG serialization is an appropriate tool for the job, RDF is not.

Practical Example

JADN defines specific digital resources that can be stored, communicated, and referenced by an RDF graph. If Bob is a physical <person> and <person> is a Class, an information model specifies selected details about Person entities in terms of their format-independent information content:

```
People = ArrayOf(Person)

Person = Record
1 name       String
2 id         Key(PersonId)
3 dob        Integer /date-adhoc
4 weight     Weight optional
5 hair_color Color optional
6 eye_color  Color optional

Color = Enumerated
1 red
2 green
```



```
3 blue
4 brown
5 black
6 white

Weight = Integer        // unit = grams

PersonId = String{pattern="..."}
```

This defines a set of properties of the Person datatype and the collection characteristics of those properties: "Record" means that the collection is both ordered and unique, which in turn means that the properties could be serialized in JSON as either maps or arrays. Formats (in this case the hypothetical /date-adhoc) indicate that the "date of birth" property is the integer number of seconds since the epoch and can be serialized using the folksy string format from the RDF example. Defining times and durations as integers in the information model allows date strings of various text representations to be compared and ordered. The Color vocabulary could contain the 140 web-safe color names, or a defined set of fashion colors such as "medium golden blonde". Enumerations allow Color strings to be both validated for semantic meaningfulness and serialized as 8- or 16-bit values.

Measuring Information

If a data instance can be losslessly converted among serializations A, B, and C, then by definition the instance conveys no more information than the smallest of its serializations.

JSON verbose serialization of <People>:

```
[{
  "weight": 79546,
  "dob": "the 4th of July 1990",
  "id": "K193-3498-234",
  "name": "Bob"
}, {
  "name": "Alice",
  "dob": "the 27th of June 1982",
  "id": "B239-5921-348"
}]
```

JSON compact serialization of <People>:

```
[
  ["Bob", "K193-3498-234", "the 4th of July 1990", 79546],
  ["Alice", "B239-5921-348", "the 27th of June 1982"]
]
```

JSON concise serialization of <People>:

```
[
  ["Bob", "K193-3498-234", 647049600, 79546],
  ["Alice", "B239-5921-348", 393984000]
]
```

CBOR serialization of <People> (converted from concise JSON):

```
56 Bytes:
82                           # array(2)
84                           # array(4)
63                           # text(3)
426F62                       # "Bob"
6D                           # text(13)
4B3139332D333439382D323334 # "K193-3498-234"
1A 26913180                  # unsigned(647049600)
1A 000136BA                  # unsigned(79546)
83                           # array(3)
65                           # text(5)
```



```
416C696365                   # "Alice"
6D                           # text(13)
423233392D353932312D333438 # "B239-5921-348"
1A 177BB800                  # unsigned(393984000)
```

This illustrates that regardless of serialization, the properties of Bob and Alice convey less than 56 bytes of information, or on average 28 bytes per person. An RDF/XML serialization could be lossless but would not supply any additional information. Information instances can be stored in a database, transmitted as XML, JSON, CBOR, or other formats, referenced by RDF graphs and included in other structured data. As with the PNG example, this suggests that information can be serialized in any suitable format, with RDF statements generated from it dynamically if needed to satisfy queries. Although this Person example does not include Bob's friends or interests, relationships can be defined within the information model or specified independently with RDF. JADN section 5.3 includes a slightly larger information model example with three types and four container and reference relationships among them.

D.3 Why JADN and not OWL?

Capture from Google Doc at
https://docs.google.com/document/d/1gY8ZaQJmJTpx8468Conchc2XVzTKE8x0WFSQT1qtB8o/edit#heading=h.ru8h2khtb5aw

The [OWL Primer] describes OWL as follows:

> The W3C OWL 2 Web Ontology Language (OWL) is a Semantic Web language designed to represent rich and complex knowledge about things, groups of things, and relations between things. OWL is a computational logic-based language such that knowledge expressed in OWL can be reasoned with by computer programs either to verify the consistency of that knowledge or to make implicit knowledge explicit.

Ontologies represent "knowledge about things", whereas IMs represent digital "things" themselves. As discussed in the body of this CN, an IM defines the essential content of entities used in computing independently of how those entities are serialized for communication or storage.

OWL has "object properties" and "data properties". Object properties are relationships between two entities and data properties are relations between an entity and a simple type. There is a rough correspondence between OWL terminology and concepts from Entity-Relationship modeling, Object Oriented Programming, and Information Modeling.

An information model models data, and the only entities in an information model are datatypes, where datatypes are either simple (a single value like string or integer) or structured (a collection of values like list or map). Translating an ontology's objects or classes into an information model's datatypes is often straightforward, but when there are alternative ways of representing the same objects as datatypes, an information model captures design decisions that are left unspecified in the ontology.

Some primary distinctions between knowledge and information models are *directionality*, *multiplicity*, *referenceability*, and *individuality*.

Directionality:

Although it may appear otherwise, an ontology is an undirected graph. Classes are connected by associations, and class associations are symmetric. If "car" and "part" are classes and a car is a composition of parts, then parts are components of car. If rose is a specialization of flower, then flower is a generalization of rose. If A is a parent of B, then B is a child of A. Arrows in an ontology diagram indicate which association term applies in the indicated direction, but the direction and term can be reversed together without changing the semantics of the graph. In contrast, an information model is a directed graph where direction determines syntax, and it has only two association types: contain and reference.

As an example, if a City datatype with name, elevation, and location properties contains a Coordinate datatype with latitude and longitude properties, one could say that Coordinate is contained_by City without changing the model. The association direction is always container to contained, or referencing to referenced. A City instance with this graph direction is serialized as:

```
{ 'name': 'Hamilton',
  'elevation': 20,
  'location': { 'latitude': 32.2912, 'longitude': -64.7864 } }
```

Reversing the direction changes the model. If Coordinate were the container it would have place, latitude, and longitude properties, while City would have just name and elevation:

```
{ 'place': { 'name': 'Hamilton', 'elevation': 20 },
  'latitude': 32.2912,
```

```
  'longitude': -64.7864 }
```

Multiplicity:

OWL defines multiplicity as an attribute of associations. Collections (associations with a maximum cardinality greater than one) also have collection attributes ordered and unique, about which OWL says:

- By default, all associations are sets; that is, the objects in them are unordered and repetitions are disallowed.
- The {ordered, nonunique} attribute is placed next to the association ends that are ordered and in which repetitions are allowed. Such associations have the semantics of lists.

In an information model, collection attributes are intrinsic to the datatype itself and don't depend on associations with other datatypes. Just as a string type always has a string value, a list type always is an ordered, nonunique collection of values. In an information model both "object properties" and "data properties" are datatypes, and a collection datatype has fixed collection attributes regardless of where it is used.

For whatever reason, {ordered, nonunique} almost never appears in ontologies. In contrast, lists are a fundamental variable type in computing and a fundamental data type in data interchange. List elements have an ordinal position and can be referenced by position. Collections that are {ordered, unique} have elements that can be referenced by either position or name, used when modeling data that can be structured as tables.

The datatype names commonly applied to collection attributes are:

collection attributes	datatype
ordered, non-unique	sequence / list
unordered, unique	set, map
ordered, unique	ordered set, record
unordered, non-unique	bag

An information model specifies collection attributes that are not explicit in an ontology in order to ensure equivalence across syntaxes.

Continuing the City example, Coordinate was assumed to be the default map type. But an information model would generally make it a list type, resulting in more compact serialized instances. All properties of type Coordinate would be serialized as lists without having to individually designate every association as {ordered, nonunique}:

```
{ 'name': 'Hamilton',
  'elevation': 20,
  'location': [32.2912, -64.7864] }
```

Defining both City and Coordinate as record types (values are {ordered, unique}) allows them to be serialized either with property names or as table rows with "name", "elevation", and "location" columns:

```
[ 'Hamilton', 20, [32.2912, -64.7864] ]
```

The record datatype specifies data that can be losslessly converted between map and table serializations (an object-relational mapping - ORM), unlike an ontology's default unordered properties which are two-column sets of key:value pairs.

Referenceability:

Ontologies treat all objects as referenceable graph nodes, which requires every object to be assigned a primary key / unique identifier. Information models represent data structures using both referenceable and non-referenceable graph nodes. Containers are used by default to define serialization. References (foreign keys) are used when necessary to avoid data duplication and recursive structures.

Individuality:

All datatypes are distinguished only by their value, but some datatypes may be individually identified by having a primary key as part of their value. The terms used for non-individual types vary, but to avoid overloaded terms such as "class type" or "type type", types can be classified as either individual or fungible. People and bank accounts are examples of individual datatypes. Measurements, observations, mass-produced parts, currency, and IP addresses are examples of fungible datatypes. Coins are fungible unless grouped by mint; bills are fungible unless an application such as fraud detection requires identification by serial number.

These characteristics result in design guidelines for constructing an information graph from an ontology graph:

1. Fungible nodes may have more than one parent.
2. Each individual node should have exactly one parent. A node with no parent has nowhere for its instances to be serialized, so any references will be dead links. An individual node with more than one parent needs a mechanism to ensure that ids are unique and a mechanism to dereference an id to the correct parent.
3. The container associations in an information model must form a set of directed acyclic graphs. Any container cycles must be broken by converting a container association to a reference, which in turn may require converting an otherwise fungible contained node to a referenceable individual node.

Appendix E. Example Information Model Source

E.1 Music Library

E.1.1 Music Library JADN

```
{
 "info": {
  "title": "Music Library",
  "package": "http://fake-audio.org/music-lib",
  "version": "1.0",
  "description": "This information model defines a library of audio tracks, organized by album",
  "license": "CC0-1.0",
  "exports": ["Library", "Album", "Track"]
 },

 "types": [
  ["Library", "MapOf", ["+Barcode", "*Album", "{1"], "", []],

  ["Barcode", "String", ["%\\d{12}"], "A UPC-A barcode is 12 digits", []],

  ["Album", "Record", [], "model for the album", [
    [1, "artist", "Artist", [], "artist associated with this album"],
    [2, "title", "String", [], "commonly known title for this album"],
    [3, "pub_data", "Publication-Data", [], "metadata about album publication"],
    [4, "tracks", "ArrayOf", ["*Track", "]0"], "individual track descriptions"],
    [5, "cover_art", "Cover-Art", [], "cover art image for this album"]
  ]],

  ["Artist", "Record", [], "interesting information about the performers", [
    [1, "artist_name", "String", [], "who is this person"],
    [2, "instruments", "ArrayOf", ["*Instrument", "]0"], "and what do they play"]
  ]],

  ["Instrument", "Enumerated", [], "collection of instruments (non-exhaustive)", [
    [1, "vocals", ""],
    [2, "guitar", ""],
    [3, "bass", ""],
    [4, "drums", ""],
    [5, "keyboards", ""],
    [6, "percussion", ""],
    [7, "brass", ""],
    [8, "woodwinds", ""],
    [9, "harmonica", ""]
  ]],

  ["Publication-Data", "Record", [], "who and when of publication", [
    [1, "label", "String", [], "name of record label"],
    [2, "rel_date", "String", ["/date"], "and when did they let this drop"]
  ]],

  ["Track", "Record", [], "information about the individual audio tracks", [
    [1, "t_number", "Number", [], "track sequence number"],
    [2, "title", "String", [], "track title"],
    [3, "length", "String", ["/time"], "length of track"],
    [4, "featured", "ArrayOf", ["*Artist"], "important guest performers"],
    [5, "audio", "Audio", [], "the all important content"]
  ]],
```



```
  ["Audio", "Record", [], "information about what gets played", [
    [1, "a_format", "Audio-Format", [], "what type of audio file?"],
    [2, "a_content", "Binary", [], "the audio data in the identified format"]
  ]],

  ["Audio-Format", "Enumerated", [], "can only be one, but can extend list", [
    [1, "MP3", ""],
    [2, "OGG", ""],
    [3, "FLAC", ""]
  ]],

  ["Cover-Art", "Record", [], "pretty picture for the album", [
    [1, "i_format", "Image-Format", [], "what type of image file?"],
    [2, "i_content", "Binary", [], "the image data in the identified format"]
  ]],

  ["Image-Format", "Enumerated", [], "can only be one, but can extend list", [
    [1, "PNG", ""],
    [2, "JPG", ""]
  ]]
 ]
}
```

E.1.2 Music Library JIDL

```
       title: "Music Library"
     package: "http://fake-audio.org/music-lib"
     version: "1.0"
 description: "This information model defines a library of audio tracks, organized by 
album"
     license: "CC0-1.0"
     exports: ["Library", "Album", "Track"]

Library = MapOf(Barcode, Album){1..*}

Barcode = String{pattern="\d{12}"}              // A UPC-A barcode is 12 digits

Album = Record                                  // model for the album
   1 artist           Artist                    // artist associated with this album
   2 title            String                    // commonly known title for this album
   3 pub_data         Publication-Data          // metadata about album publication
   4 tracks           ArrayOf(Track) [1..*]     // individual track descriptions
   5 cover_art        Cover-Art                 // cover art image for this album

Artist = Record                                 // interesting information about the 
performers
   1 artist_name      String                    // who is this person
   2 instruments      ArrayOf(Instrument) [1..*]// and what do they play

Instrument = Enumerated                         // collection of instruments (non-
exhaustive)
   1 vocals
   2 guitar
   3 bass
   4 drums
   5 keyboards
   6 percussion
   7 brass
   8 woodwinds
   9 harmonica
```



```
Publication-Data = Record                        // who and when of publication
   1 label              String                   // name of record label
   2 rel_date           String /date             // and when did they let this drop

Track = Record                                   // information about the individual audio
tracks
   1 t_number           Number                   // track sequence number
   2 title              String                   // track title
   3 length             String /time             // length of track
   4 featured           ArrayOf(Artist)          // important guest performers
   5 audio              Audio                    // the all important content

Audio = Record                                   // information about what gets played
   1 a_format           Audio-Format             // what type of audio file?
   2 a_content          Binary                   // the audio data in the identified format

Audio-Format = Enumerated                        // can only be one, but can extend list
   1 MP3
   2 OGG
   3 FLAC

Cover-Art = Record                               // pretty picture for the album
   1 i_format           Image-Format             // what type of image file?
   2 i_content          Binary                   // the image data in the identified format

Image-Format = Enumerated                        // can only be one, but can extend list
   1 PNG
   2 JPG
```

E.1.3 Music Library Tables

.	.
title:	Music Library
package:	http://fake-audio.org/music-lib
version:	1.0
description:	This information model defines a library of audio tracks, organized by album
license:	CC0-1.0
exports:	Library, Album, Track

Type Name	Type Definition	Description
Library	MapOf(Barcode, Album){1..*}	

Type Name	Type Definition	Description
Barcode	String{pattern="\d{12}"}	A UPC-A barcode is 12 digits

Type: Album (Record)

ID	Name	Type	#	Description
1	**artist**	Artist	1	artist associated with this album
2	**title**	String	1	commonly known title for this album

ID	Name	Type	#	Description
3	**pub_data**	Publication-Data	1	metadata about album publication
4	**tracks**	ArrayOf(Track)	1..*	individual track descriptions
5	**cover_art**	Cover-Art	1	cover art image for this album

Type: Artist (Record)

ID	Name	Type	#	Description
1	**artist_name**	String	1	who is this person
2	**instruments**	ArrayOf(Instrument)	1..*	and what do they play

Type: Instrument (Enumerated)

ID	Name	Description
1	**vocals**	
2	**guitar**	
3	**bass**	
4	**drums**	
5	**keyboards**	
6	**percussion**	
7	**brass**	
8	**woodwinds**	
9	**harmonica**	

Type: Publication-Data (Record)

ID	Name	Type	#	Description
1	**label**	String	1	name of record label
2	**rel_date**	String /date	1	and when did they let this drop

Type: Track (Record)

ID	Name	Type	#	Description
1	**t_number**	Number	1	track sequence number
2	**title**	String	1	track title
3	**length**	String /time	1	length of track
4	**featured**	ArrayOf(Artist)	1	important guest performers
5	**audio**	Audio	1	the all important content

Type: Audio (Record)

ID	Name	Type	#	Description
1	**a_format**	Audio-Format	1	what type of audio file?
2	**a_content**	Binary	1	the audio data in the identified format

Type: Audio-Format (Enumerated)

ID	Name	Description
1	**MP3**	
2	**OGG**	
3	**FLAC**	

Type: Cover-Art (Record)

ID	Name	Type	#	Description
1	**i_format**	Image-Format	1	what type of image file?
2	**i_content**	Binary	1	the image data in the identified format

Type: Image-Format (Enumerated)

ID	Name	Description
1	**PNG**	
2	**JPG**	

Appendix F. Notices